Experimental Study for Detection of Leaks in Horizontal Pipelines

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Abstract

This document presents an experimental study of the flow behavior and pressure of liquids in horizontal pipes, in the presence and absence of leaks in a transitory state. For the development of the investigation, an experimental assembly was constructed in the Fluid Mechanics laboratory of the Francisco de Paula Santander University Ocaña (UFPSO). To simulate the leakage in water conduction in pipes, two pressure sensors and two flow sensors were installed at the beginning and at the end of the pipe to measure the pressure and flow in the system, a data acquisition equipment and a Virtual Instrument that was developed in the labview Software that allows detecting a leak in real time was used, ensuring its presence and correction immediately. Finally, experimental tests were carried out to obtain data on the physical variables of the flow and pressure sensors at the inlet and outlet. With these data, a dynamic model was made of the pipe observed from each sensor, when the system is not leaking, and then the same procedure was made for the system when leaks occur. This simulation was performed using Matlab's PID Tuning application.
Keywords: PID Tunind, modeling, Hydraulic pipes, fault detection, pipeline monitoring, diagnostic systems

1. Introduction

Pipelines are important means of transporting petroleum products. Therefore, leakage monitoring is important in pipeline management for safety and environmental reasons, pipeline leak location and detection systems fall into three categories: external or hardware-based methods, internal or software-based methods and non-technical methods or visual inspection. Methods based on external technology detect leaks using fiber optic or dielectric cables installed along pipelines, while internal methods use instruments to monitor internal pipeline parameters such as pressure, flow or temperature at the ends of the pipeline and use these parameters to infer leakage by computation, such as the volume balance method where the importance of the packing term in the transient flow is emphasized [1] and [2]. Visual inspection methods. These methods include trained personnel or a specially trained dog, along with their trainer, to walk along the pipeline or inspect the pipeline of a manned or unmanned aircraft to obtain visual or other evidence of leaks. The disadvantage of these methods is that detection depends on the frequency of inspection. The accuracy of the method also depends on the inspector’s experience and skill. Finally, buried pipelines are not accessible for visual inspection.

This research focuses on leak detection techniques with possible application in pipelines [5]. This issue is of great importance because pipeline failures have serious consequences, such as human losses and irreparable damage to the environment [6].

This document is organized as follows: section 2 presents the development of the experimental set-up; section 3 presents the dynamic models of the system; section 4 shows the results; and section five presents the conclusions.

2. Development of the Experimental Set-up

2.1. Hydraulic system

The experimental test bench was carried out in the Fluid Mechanics laboratory of the Universidad Francisco de Paula Santander Ocaña (UFPSO). For its assembly it was necessary to use 2 glass containers of 0.4 m long, 0.3 m wide and 0.3 m high, with a thickness of 5 mm, two pumps to transfer the fluid from one tank to another, 4 bases or supports to maintain a Δz = 0 and pipes and fittings of ½ inch. See figure 1.
2.2 Instrumentation Selection Criteria

For the Experimental set-up the Instruments that appear in table 1 were selected:

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Characteristics</th>
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| **Pressure Sensors** | - 4 to 20 mA analog output.  
- Measuring ranges: 0 to 60 psi required by the pump  
- Cost adjusted to budget  
- Accuracy ± 0.25%.  
- Repeatability ≤ ± 0.1 % |
| **Flow rate sensors**| - 4 to 20 mA analog output.  
- Measuring ranges: 0 to 35 L/min required by the pump  
- Cost adjusted to budget  
- Accuracy ± 5%.  
- Repeatability ≤ ± 1 % |
| **Data Acquisition System** | NI cDAQ-9178 Chassis  
NI 9203 module (Figure 20) 4 to 20 mA analog input. |

2.3 Instrument Calibration

Calibration is the set of operations with which, under certain specific conditions, the correspondence is established between the values indicated in an Instrument, equipment or measuring system, or by the values represented by a materialized measure or reference material and the known values corresponding to a measure or standard, thus ensuring the traceability of the measurements to the corresponding basic units and procedure to their adjustment or expressing this correspondence by means of tables or correction curves [4].

In order to calibrate the pressure sensor, tests were performed where the pressure value was changed (taking into account that this sensor allows a visualization through an indicator with a display where the data is shown digitally and analogically in real time) and then it was related to the values obtained in mA with
the data acquisition module, obtaining through Curve Fitting (MATLAB), as shown in equation 1.

\[ f(x) = p_1 \times x + p_2 \tag{1} \]

where,

\[ p_1 = 9256 \]
\[ p_2 = -37.09 \]

With an adjustment of \( R = 0.9935 \)

For the characterization of the Flow rate sensor, tests were performed where the Flow value was changed (taking into account that this sensor has an operating range from 2 to 50 L/min and that the outputs are from 4 to 24 mA) and then it was related to the values obtained in mA with the data acquisition module, obtaining through Curve Fitting (MATLAB), the equation 2:

\[ f(x) = p_1 \times x + p_2 \tag{2} \]

Where,

\[ p_1 = -0.1372 \]
\[ p_2 = 1.677 \]

With an adjustment of \( R = 0.9791 \)

### 2.4 Virtual Instrument Design

For the development of the research, a user interface was created, which provides the operator with flow and pressure data, graphs and controls for the correct visualization and automation of the leak detection system.

The user interface must be designed with the tools to be used by the operator; it should not be designed exclusively to meet the functional requirements, but should also be easy to use and should allow the operator to select settings that are variable such as time and number of data to measure. The design of this parameter should facilitate the operator's work by displaying the system completely on a screen [3].

Figure 2 shows the welcome screen, a presentation screen containing all the application information was designed for this instrument, which included the application name, logos, and a schematic of the design of the pipe bench experiment.

On figure 3, the screen shows the graphs of the input flow, the output flow, the input pressure, the output pressure. It is possible to visualize independently how each signal behaves and the data taken from the system is visualized in a table. In this same screen, when the differences in flow rates and pressure are lower than the lower limit established in the leak detection algorithm, a message is displayed that says "a leak has been detected".
3. System model

In this section, the adopted models are presented. Matlab’s PID Tuning application was used, allowing obtaining graphical results observed below. Data was obtained from the physical variables of the flow and pressure sensors at the inlet and outlet, with these data a dynamic model of the pipe observed from each sensor was made, when the system does not present leaks, then the same procedure of the system was made when leaks exist and a comparison is made between each of the models.

3.1 Dynamic system models in the absence of leaks

The system seen from the point of view of each of the fixed variables is assimilated to a behavior of a first-order system, whose transfer function can be seen in equation 3:

\[ F_1 = \frac{K}{T_1 \cdot s + 1} \]  

(3)

For the system model viewed from the input flow as shown in figure 4, the transfer function variables are:

\[ K = 0.99917 \quad \text{and} \quad T_1 = 1 \times 10^{-6} \]
For the system model viewed from the output flow, the transfer function variables are:

\[ K = 1.0001 \quad \text{and} \quad T_1 = 1.6244 \]

For the system model seen from the input pressure, the transfer function variables are:

\[ K = 1.005 \quad \text{and} \quad T_1 = 9.0455 \]

For the system model seen from the output pressure, the transfer function variables are:

\[ K = 0.99917 \quad \text{and} \quad T_1 = 1 \times 10^{-6} \]

### 3.2 Dynamic system models in the presence of leaks

For the system model seen from the input flow, the transfer function variables are:

\[ K = 1.0004 \quad \text{and} \quad T_1 = 1.5806 \]

For the system model seen from the output flow, the transfer function variables are:

\[ K = 1.0001 \quad \text{and} \quad T_1 = 1.7055 \]

For the system model viewed from the inlet pressure, the transfer function variables are:

\[ K = 1.0007 \quad \text{and} \quad T_1 = 9.502 \]

For the system model seen from the output pressure, the transfer function variables are:

\[ K = 1.0002 \quad \text{and} \quad T_1 = 1.7583 \]

### 4. Results

In figure 5, it can be observed in the behavior of the flow signals that when there is
a leak, the flow from the output sensor drops. In order to detect the leak the mass conservation model and a leak detection algorithm described in [7] is used.

![Flow signals](image1)

Figure 5. Behavior of flow signals in the presence and absence of leakage.

In figure 6, the behavior of the pressure signals is observed, when there is a leak the pressure raises and the flow drops.

![Pressure signals](image2)

Figure 6. Behavior of Pressure Signals in the Presence and Absence of Leakage.

Figure 7 shows the implementation of the virtual instrument to validate and evaluate the behaviour of the system. In this figure it is possible to visualize the graphic interface of the VI when it is in operation, allowing direct observation of the data obtained in real time from the pressure and flow rate sensors of both the inlet and the outlet.

![Virtual instrument interface](image3)

Figure 7. Leak Detection VI Graphical Interface.
Figure 8 shows the precise instant in which a leak occurs on the pipe test bench; this is made known by means of an alarm specifying that there is a leak, thus allowing immediate action to be taken on the problem.

![Figure 8. Leak Detection VI Graphical Interface (instant leak is detected).](image)

5. Conclusions

Based on the information obtained by the sensors, models of the system were made in the absence and presence of leakage. Inlet pressures of around 13.2 psi and outlet pressures of 6 psi and inlet and outlet flows of approximately 27 L/min were found, marking the operation of the bench with no leaks. However, when a leak occurred, the system made it possible to recognize the increase in pressure and the reduction in flow, obtaining data of up to approximately 24 L/min at the outlet.

The use of this data acquisition system makes it possible to detect a leak in real time, guaranteeing its presence and correction immediately, and bearing in mind that this can reduce the problem that arises behind a leak.

References


Experimental study for detection of leaks in horizontal pipelines


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